FC

Investigations Division Technical Note No 13

The use of Belmont tower wind data to assess the advisability of using the geostrophic wind direction for runway selection in light surface wind conditions.

A D Browne Met O 9

Introduction

During discussions with the CAA on the topic of wind shear Met O 9 have raised the point that, in conditions when the surface wind is light, the overall safety of landing operations could probably be improved by taking some account of the upper wind direction (eg gradient or geostrophic wind direction) when choosing the most appropriate runway to use for take-off and landing. Within the general context of landing operations, particularly in the presence of abnormal wind shear, it is the wind profile over the lowest several hundred feet and not solely the wind at the surface, that is of importance to the pilot.

It appears that current practice, in light surface wind situations, is for ATC to use those runways which cause the least (noise) nuisance to the surrounding population. In these circumstances there is a possibility that potentially hazardous situations may arise, albeit rarely, in which aircraft take-off with near zero surface wind along the runway shearing to a strong tail wind aloft or land with a strong tail wind aloft shearing to a light head wind near the surface, a configuration which contributed to the crash of a DC-10 at Logan Airport in December 1973 (AWST 1975[1,2]). The purpose of the study reported here was to examine the strength of the relationship between the geostrophic wind direction and the actual wind direction at about 1500 ft, in light surface wind conditions, with a view to using the geostrophic wind direction as an indicator of the upper flow in such circumstances. A comparison of the geostrophic wind direction and the actual wind direction at a lower level, around 200-500 feet, would have been preferable for such a study, but the 1275 ft Belmont data provided the only reliable and continuous source of wind information (within the UK) for analysis.

Description of the Data

The airfields selected for this study were Manby (1.9.73-30.11.73) and Waddington (1.12.73-31.8.74)*. Manby Airfield (63 ft AMSL) is situated on the coastal plain about 13 km east of Belmont and 13 km from the sea. Waddington Airfield is situated on the Lincoln ridge about 32 km south-west of Belmont and 224 ft AMSL. The climatologies (1962-71) of the surface winds at Manby and Waddington are similar although Waddington appears to be more exposed, having winds in the range 0-5 kn on about 18% of all hours while Manby has 24% of winds in this category (Meteorological Office[3]). The observed frequency in the combined Manby and Waddington data set was 19% and no dramatic changes in the distribution of winds throughout the year were noted (see Fig 1).

For data representative of the winds an aircraft would experience on the approach into the airfields, data were selected from the records of the Belmont IBA Television mast (instrumented by the CEGB). The mast is situated on the west of a low ridge running NNW-SSE and the base is 411 ft AMSL. Data were taken from the top anemometer at a level of 1275 ft (1686 ft AMSL) because the anemometer at 680 ft was shielded from north westerly winds by the structure of the tower; see Fig 2 for a good illustration of this 'tower-shadow' effect. The observations consisted of mean winds (averaged over the previous hour) taken at three-hourly intervals when the surface wind at Manby or Waddington was 5 kn or below.

The geostrophic wind direction over Lincolnshire was extracted from the UK hourly charts and, together with the tower wind, it can be taken as being representative of a large area around Belmont encompassing both Manby and Waddington.

* Waddington data was not available for the first three months of the period chosen.

Summary of Data used in Investigation

Surface winds less than or equal to 5 kn at:-

Manby	53°21'N 0°5'E	63 ft AMSL	1.9.73-30.11.73
Waddington	53°10'N 0°31'W	224 ft AMSL	1.12.73-31.8.74

Tower winds (when surface wind $\leq$ 5 kn) at:-

Belmont	53°20'N 0°8'W	411 ft AMSL	1. 9.73-31.8.74

Anemometer 1275 ft above base, 1623 ft above Manby and 1462 ft above Waddington.

Geostrophic wind direction over Lincolnshire 1.9.73-31.8.74.

Treatment of Data

The data underwent quality control to eliminate the large majority of systematic transcription errors and was prepared in a form suitable for examination using the BMD statistics package. Bivariate scatter plots were produced for various combinations of variables and these revealed considerable scatter in the relationship between the tower and geostrophic wind directions. A large part of this scatter occurred when the tower wind was low as can be seen by comparing Figs 3 and 4. It was decided to divide the data into categories of tower wind speed above and below 10 kn. A threshold of 10 kn implies a maximum vector difference of 15 kn between the tower and surface winds; differences of this magnitude or less would be relatively unimportant and are encountered on approximately 90% of all daylight hours (Hardy 1974[4]). Similarly the data was categorized into 'day' and 'night' classes to take account of the different boundary layer regimes during these periods. The distribution of tower wind speeds throughout the day is shown in Fig 5. The 'day' class included the Ø9ØØ, 12ØØ, 15ØØ and 18ØØZ observations, which covers the period of the large majority of aircraft movements (Ø73Ø to 193ØZ). An alternative 'day' class was used including the 21ØØ observation to include the period of evening flights. Using this categorization a computer programme was written to prepare statistics of wind direction differences; this allowed tower-geostrophic and tower-surface direction differences to be compared and the results are set out in tables 1 to 4.

Discussion of Results

For reasons previously noted the most important results to study are the 'day' tables with a tower wind speed of 10 kn or more. Comparing the standard deviations of tower-geostrophic differences with tower-surface differences it is clear that the spread of the tower-surface differences is much larger. This result is hardly surprising in view of the turbulent nature of the Ekman boundary layer and the fact that the average tower-geostrophic direction differences are not significantly different from zero suggests that the tower anemometer is close to the top of the Ekman layer. The decrease of the variability at night while the backing of the surface wind increases from around 25° to 45° is also well recognised (Hoxit 1975[5]).

When speaking of the numbers of differences exceeding certain thresholds, these have been taken with reference to the average backing during that period. The period chosen is the Ø9ØØ-18ØØ 'day' with a tower wind speed ≥ 10 kn unless otherwise stated. The results show that if the geostrophic wind is used as an estimate of the wind direction above the airfield the number of occasions when the direction difference or error is 30° or more is 19 times out of 70 or 27%. The distribution of differences does not differ significantly from a normal distribution for which the percentage of differences exceeding 30° is 35% (see Appendix). The differences between tower wind direction and surface wind direction exceeding 30° number 30 out of 71 or 42%, and when the distribution was plotted on probability graph paper (Fig C in Appendix) it was obviously far from normal as a chi-square test revealed. The only distributions that were approximately normal were the 'day' tower-geostrophic differences for all tower wind speeds. The inclusion in the 'long day' class of the 21ØØZ observation reduced the standard deviation of the tower-geostrophic and tower-surface differences in all cases when the tower wind speed was greater than 10 kn. In order to compare the value of the geostrophic and surface wind as estimates of the tower wind the numbers of differences exceeding certain threshold values are listed in tables 5-8 together with details on undefined geostrophic and surface winds.

Conclusions

On the basis of the data examined in this note, for the 'day' hours of Ø9ØØ-18ØØ inclusive, in conditions when the surface wind is light (less than or equal to 5 kn) and the upper (~ 1500 ft) wind speed is 10 kn or above, the geostrophic wind direction appears to be a reasonable indicator of the upper wind direction, being within 30 degrees of the latter on 73% of occasions. Under the same set of circumstances the surface wind direction is, as expected, not as good an indicator of the upper wind direction, being within 30 degrees on only 58% of occasions (taking into account the average backing of the surface wind).

In general we can expect that the stronger the upper flow, the better will be the agreement between the geostrophic and actual upper wind direction.

For purposes of deciding on the most suitable runway in light surface-wind conditions, the CAA may therefore like to consider making use of the gradient or geostrophic wind direction, which can be supplied by the local meteorological office, more particularly when the gradient wind speed is in excess of 20 or 30 kn. Such conditions obviously imply the existence of significant vertical wind shear within the lowest 2000 ft, and the practice of landing and taking-off into the direction of the upper wind would go some way towards minimizing any potential hazard in most such situations. The exceptions are those cases when a large change in head wind occurs over a very short time or distance near the surface on the approach; in that instance a sudden loss of head wind near the surface must be considered to be potentially more hazardous than an equivalent sudden increase in head wind close to the ground (below about 100 ft). However above about 200 ft, the latter case (sudden increase of head wind) can prove equally hazardous if the pilot fails to re-apply sufficient power shortly after making the initial power reduction; a high rate of descent can develop if this re-application is not made promptly. It would also be desirable, if not essential, in these circumstances for the pilot to be advised of the estimated 2000 ft wind and alerted to the possibility of hazardous wind shear on the approach or climb-out. On receipt of an alert or warning of this type during

the approach the pilot may be able to check, and/or continuously monitor the wind along the glide-slope, provided the aircraft is suitably instrumented.

Several points should be noted with regard to these conclusions however.

1. The surface wind data used was based on a ten-minute averaging period while ATC report winds averaged over a much shorter period of typically 10-15 seconds (Dutton 1975[6]) and the increase of variability associated with such short period averages would tend to produce a larger variance of tower-surface wind direction differences than indicated in this note.

2. The direction differences tended to persist for several hours in the same sense. Differences of $\pm 50^{\circ}$ persisted for 3 or more hours in approximately 20% of occasions. In such situations, feedback from the pilots, in the form of wind reports whenever possible, would be of help to ATC in obtaining a better estimate of the upper wind direction.

References

1. Aviation Week and Space Technology, April 7 1975, pages 54-59, NTSB assays Iberia accident at Logan.
2. Aviation Week and Space Technology, April 14 1975, pages 53-56, Wind factor studied in Iberia crash.
3. Meteorological Office Annual Wind Summaries (velocity and direction).
4. Hardy, R. N. 1974, Meteorological Office IDM No 109.
5. Hoxit, L. R. 1975, Boundary Layer Meteorology Vol 8 (1975), Diurnal variations in the planetary boundary-layer winds over land.
6. Dutton, M. J. O., 1975, Meteorological Magazine Vol 104 (1975), Optimum averaging time of wind reports for aviation.

Table 1(a) Tower Wind–Geostrophic Wind Direction Differences

Normal Day ØØØØ–18ØØ

Data consists of 193 observations including 49 cases of undefined wind direction and 16 cases of missing tower data

Number of cases per ten degree range

Tower Wind Speed	≤ −61	−60 to −51	−50 to −41	−40 to −31	−30 to −21	−20 to −11	−10 to − 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
< 10 kn	6	3	5	4	8	1	5	5	9	0	5	5	2	8	66	2.7	56.2
≥ 10 kn	2	3	2	4	9	10	7	11	9	5	2	4	1	1	70	−0.3	32.4
All	8	6	7	8	17	11	12	16	18	5	7	9	3	9	136	−0.9	45.5

Table 1(b) Tower Wind–Surface Wind Direction Differences

Normal Day ØØØØ–18ØØ

Data consists of 193 observations including 16 cases of undefined wind direction and 16 cases of missing tower data

Number of cases per ten degree range

Tower Wind Speed	≤ −61	−60 to −51	−50 to −41	−40 to −31	−30 to −21	−20 to −11	−10 to − 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
< 10 kn	7	4	1	4	4	6	3	6	5	3	6	10	8	23	90	23.6	63.6
≥ 10 kn	4	1	1	1	1	5	4	4	8	7	12	6	5	12	71	24.0	57.9
All	11	5	2	5	5	11	7	10	13	10	18	16	13	35	161	23.8	61.0

Table 2(a) Tower Wind–Geostrophic Wind Direction Differences

Normal Night 21ØØ–Ø6ØØ

Data consists of 374 observations including 50 cases of undefined wind direction and 26 cases of missing tower data

Tower Wind Speed		Number of cases per ten degree range															
	≤ −61	−60 to −51	−50 to −41	−40 to −31	−30 to −21	−20 to −11	−10 to − 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
< 10 kn	20	3	2	7	4	4	6	12	7	6	8	6	3	15	103	−3.5	64.4
≥ 10 kn	6	0	6	8	15	31	43	26	39	4	10	4	3	3	198	−2.7	25.9
All	26	3	8	15	19	35	49	38	46	10	18	10	6	18	301	−3.0	43.0

Table 2(b) Tower Wind–Surface Wind Direction Differences

Normal Night 21ØØ–Ø6ØØ

Data consists of 374 observations including 56 cases of undefined wind direction and 26 cases of missing tower data

Tower Wind Speed		Number of cases per ten degree range															
	≤ −61	−60 to −51	−50 to −41	−40 to −31	−30 to −21	−20 to −11	−10 to − 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
< 10 kn	8	1	1	2	2	1	2	8	6	5	10	8	4	42	100	37.8	66.9
≥ 10 kn	3	2	2	1	3	4	6	7	13	21	32	28	27	46	195	38.0	39.1
All	11	3	3	3	5	5	8	15	19	26	42	36	31	88	295	37.9	50.1

Table 3(a) Tower Wind–Geostrophic Wind Direction Differences

All Hours

Data consists of 567 observations including 99 cases of undefined wind direction and 42 cases of missing tower data

Tower Wind Speed		Number of cases per ten degree range															
		≤ −61	−60 to −51	−50 to −41	−40 to −31	−30 to −21	−20 to −11	−10 to − 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
<	10 km	26	6	7	11	12	5	11	17	16	6	13	11	5	23	169	−1.1	61.2
≥	10 km	8	3	8	12	24	41	50	37	48	9	12	8	4	4	268	−3.1	27.7
	All	34	9	15	23	36	46	61	54	64	15	25	19	9	27	437	−2.3	43.8

Table 3(b) Tower Wind–Surface Wind Direction Differences

All Hours

Data consists of 567 observations including 72 cases of undefined wind direction and 42 cases of missing tower data

Tower Wind Speed		Number of cases per ten degree range															
		≤ −61	−60 to −51	−50 to −41	−40 to −31	−30 to −21	−20 to −11	−10 to − 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
<	10 km	15	5	2	6	6	7	5	14	11	8	16	18	12	65	190	31.1	65.6
≥	10 km	7	3	3	2	4	9	10	11	21	28	44	34	32	58	266	34.3	45.2
	All	22	8	5	8	10	16	15	25	32	36	60	52	44	123	456	32.9	54.6

Table 4(a) Tower Wind-Geostrophic Wind Direction Differences

Long Day ØØØØ-21ØØ

Data consists of 290 observations including 61 cases of undefined wind direction and 22 cases of missing tower data

Number of cases per ten degree range

Tower Wind Speed	≤ -61	-60 to -51	-50 to -41	-40 to -31	-30 to -21	-20 to -11	-10 to - 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
< 10 kn	15	3	7	6	9	2	6	6	10	3	5	7	2	11	92	-4.6	61.3
≥ 10 kn	5	3	3	5	13	23	20	17	20	5	3	4	1	2	124	-4.1	29.4
All	20	6	10	11	22	25	26	23	30	8	8	11	3	13	216	-5.5	45.6

Table 4(b) Tower Wind-surface Wind Direction Differences

Long Day ØØØØ-21ØØ

Data consists of 290 observations including 31 cases of undefined wind direction and 22 cases of missing tower data

Number of cases per ten degree range

Tower Wind Speed	≤ -61	-60 to -51	-50 to -41	-40 to -31	-30 to -21	-20 to -11	-10 to - 1	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	≥ 60	TOTAL	MEAN	SD
< 10 kn	11	4	2	4	6	6	4	8	7	4	8	10	9	31	114	21.3	66.6
≥ 10 kn	5	3	2	2	3	9	5	5	14	14	23	9	12	18	124	23.1	52.0
All	16	7	4	6	9	15	9	13	21	18	31	19	21	49	238	22.3	59.3

Table 5 Number of Occasions when wind direction differences exceed certain values

Normal Day Ø9ØØ–18ØØ

Tower Wind Speed		Geostrophic* ≥30°	≥40°	≥50°	Undefined Geo Drn	Surface* ≥30°	≥40°	≥50°	Undefined Surface Drn
<	10 km	38(58)	29(44)	19(29)	33	55(61)	43(48)	35(39)	8
≥	10 km	19(27)	13(19)	7(10)	5	30(42)	23(32)	18(25)	4
	All	57(42)	42(31)	26(19)	38	85(53)	66(41)	53(33)	12

Table 6 Number of Occasions when wind direction differences exceed certain values

Normal Night 21ØØ-Ø6ØØ

Tower Wind Speed		Geostrophic ≥30°	≥40°	≥50°	Undefined Geo Drn	Surface ≥30°	≥40°	≥50°	Undefined Surface Drn
<	10 km	64(62)	52(50)	43(42)	31	55(55)	44(44)	34(34)	32
≥	10 km	38(19)	24(12)	14(7)	11	54(28)	39(20)	28(14)	14
	All	102(34)	76(25)	57(19)	42	109(37)	83(28)	62(21)	46

Table 7 Number of Occasions when wind direction differences exceed certain values

All Hours

Tower Wind Speed		Geostrophic ≥30°	≥40°	≥50°	Undefined Geo Drn	Surface ≥30°	≥40°	≥50°	Undefined Surface Drn
<	10 km	102(60)	78(46)	60(36)	64	111(58)	88(46)	77(41)	40
≥	10 km	59(22)	35(13)	19(7)	16	96(36)	65(24)	46(17)	18
	All	161(37)	113(26)	79(18)	80	207(45)	153(34)	123(27)	58

Table 8 Number of Occasions when wind direction differences exceed certain values

Long Day Ø9ØØ–21ØØ

Tower Wind Speed		Geostrophic ≥30°	≥40°	≥50°	Undefined Geo Drn	Surface ≥30°	≥40°	≥50°	Undefined Surface Drn
<	10 km	55(60)	45(49)	34(37)	41	73(64)	58(51)	44(39)	18
≥	10 km	27(22)	19(15)	12(10)	7	54(44)	33(27)	25(20)	7
	All	82(38)	64(30)	46(21)	48	127(53)	91(38)	69(29)	25

Figures in brackets indicate percentage of total.

* In Tables 5-8 : 'Geostrophic' is abbreviation for 'Tower-geostrophic wind direction difference'
'Surface' is abbreviation for 'Tower-surface wind direction difference'

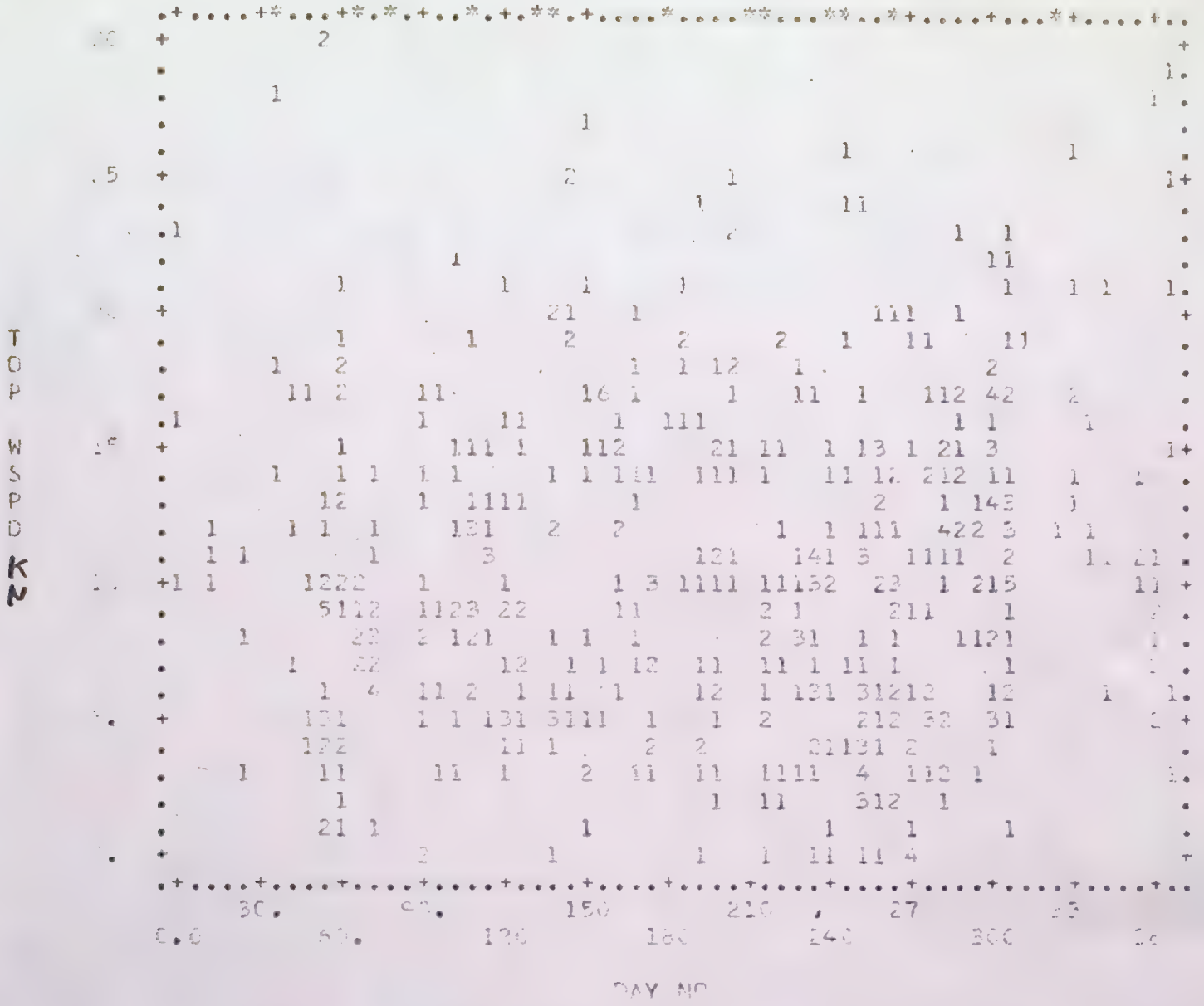


Fig 1 Distribution of Tower Wind Speeds throughout year

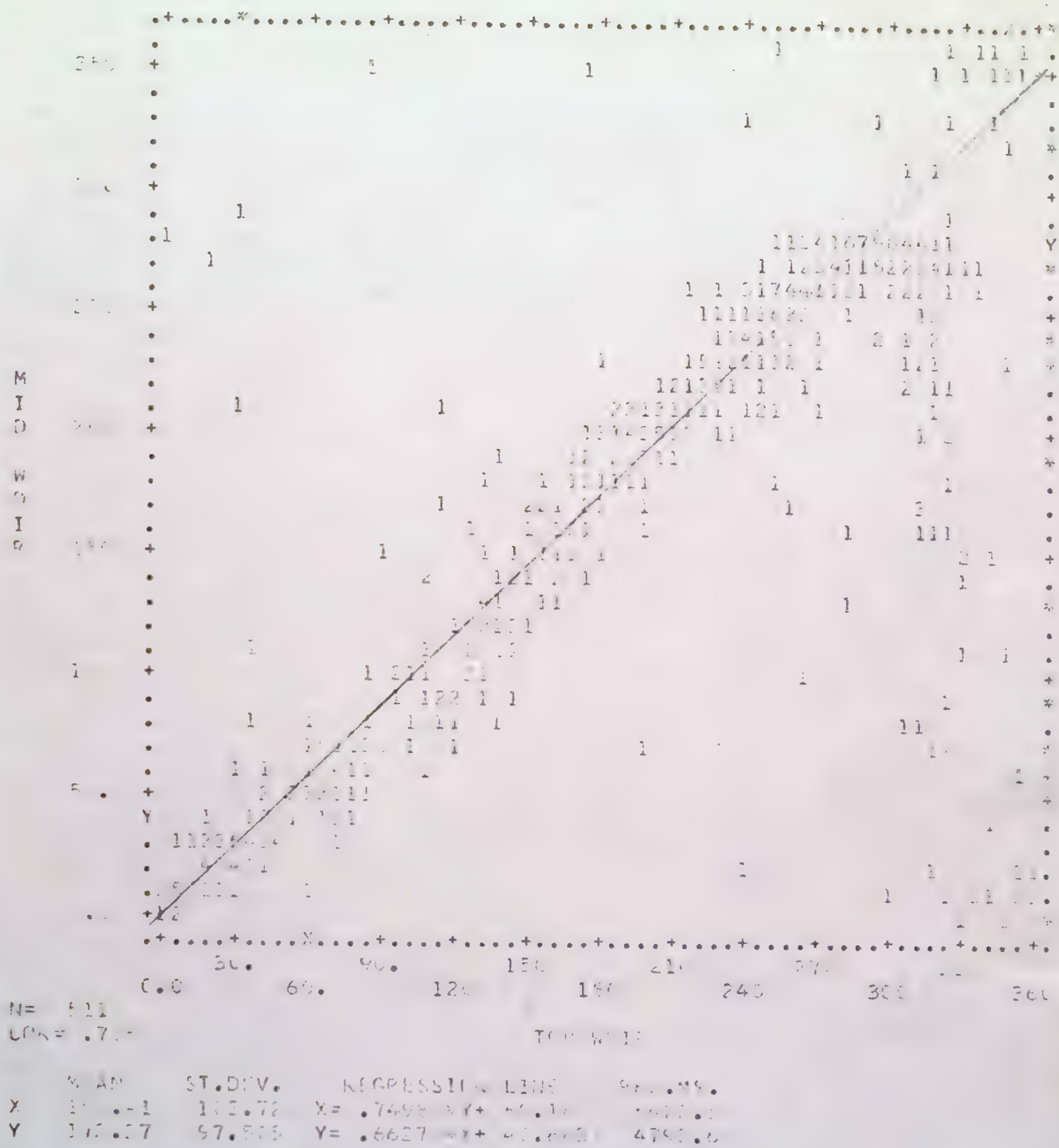
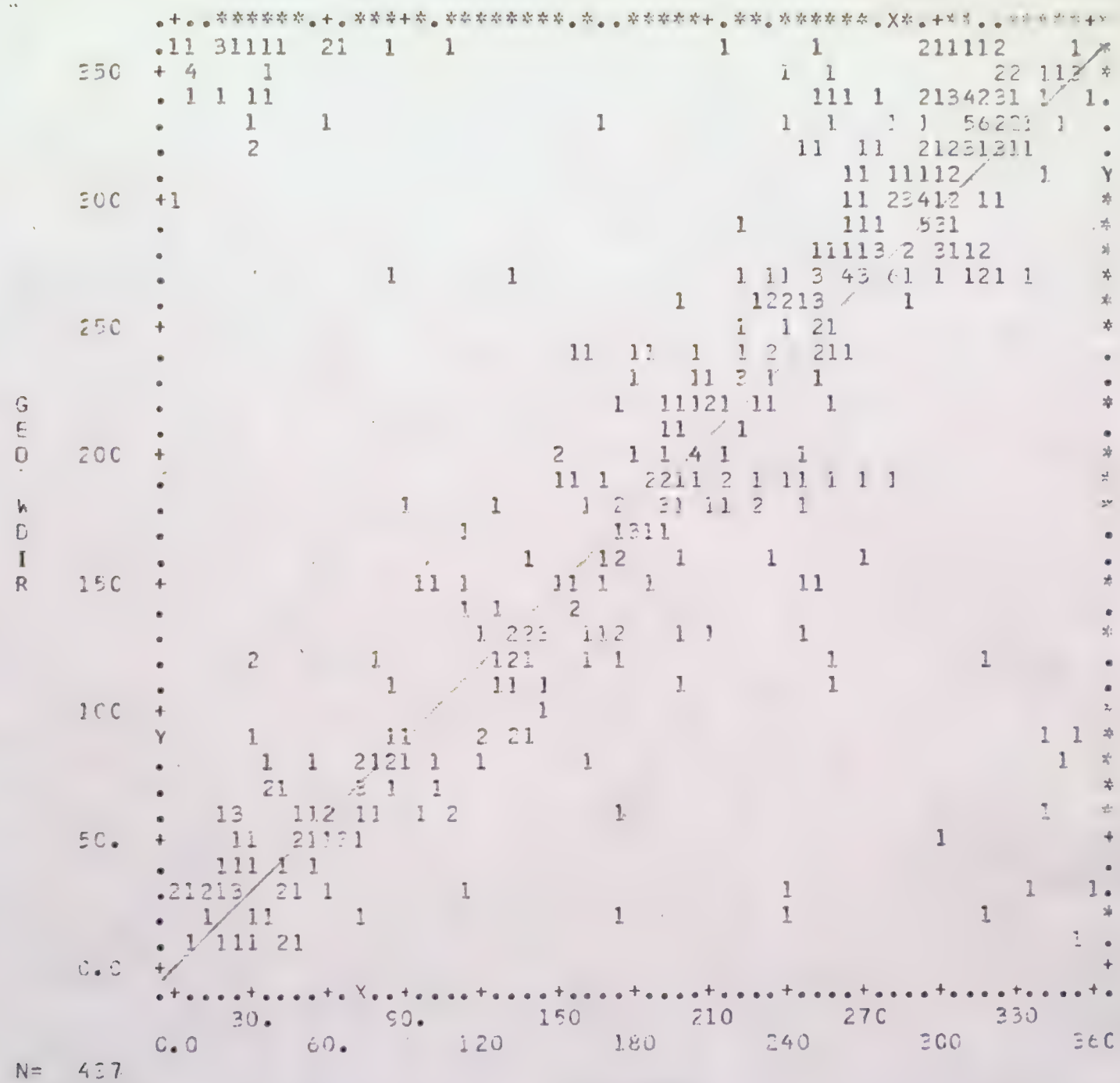


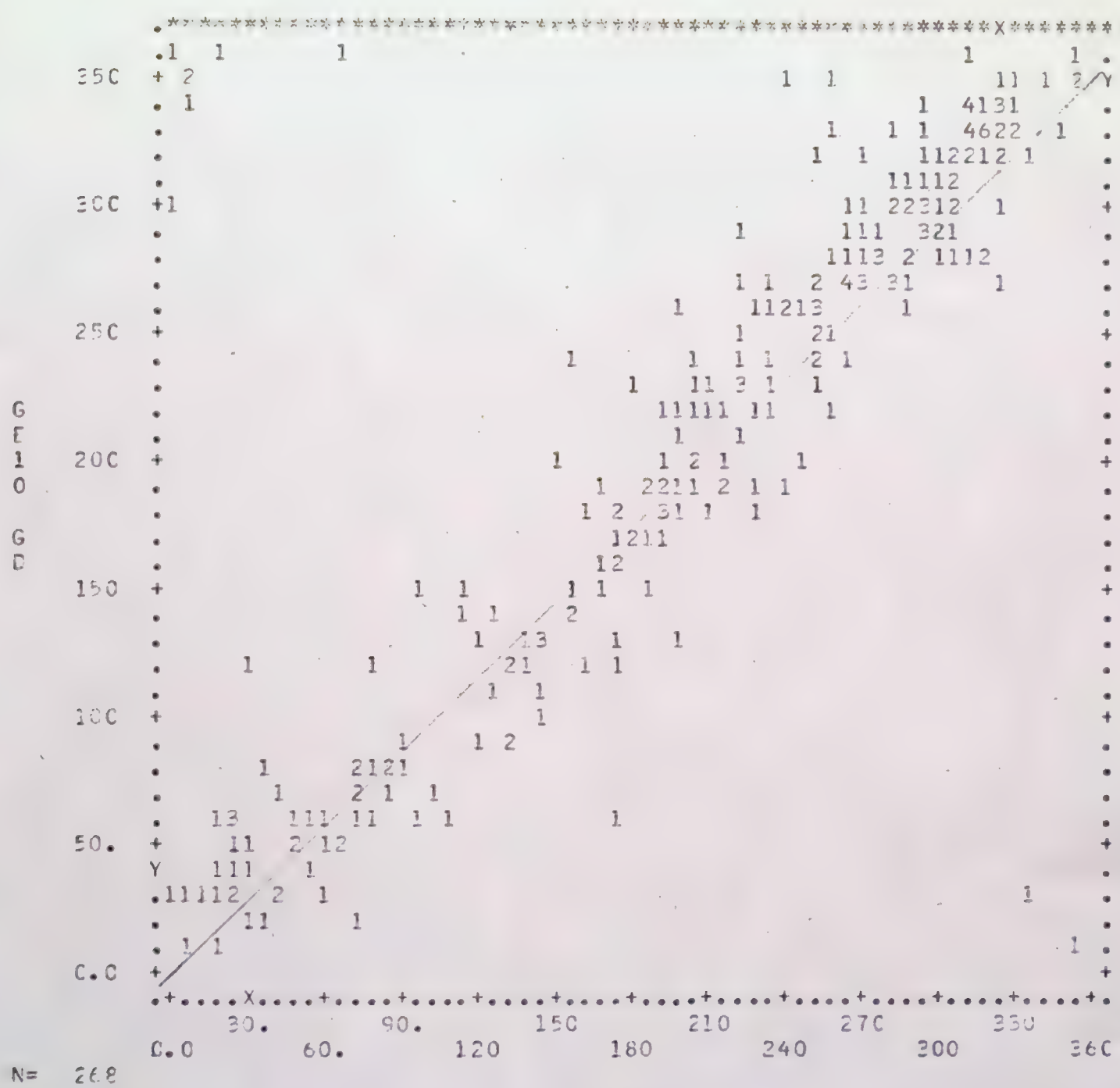
Fig 2 Scatter Plot of Mid Wind Direction against Top Wind Direction showing 'tower-shadow' effect



N= 437
CCR= .574

	MEAN	ST.DEV.	REGRESSION LINE	RES.MS.
X	198.57	105.01	X= .55292*Y+ 79.743	7411.4
Y	214.92	109.02	Y= .89590*X+ 98.387	7987.6

Fig 3 Scatter Plot of Geostrophic Wind Direction against Tower Wind Direction



	MEAN	ST.DEV.	REGRESSION LINE	RES.MS.
X	203.58	101.07	X= .77495*Y+ 38.186	3780.5
Y	213.43	103.03	Y= .81464*X+ 47.583	3674.1

Fig 4 Scatter Plot of Geostrophic Wind Direction against Tower Wind Direction when the Tower Wind Speed was greater than or equal to 10 kn

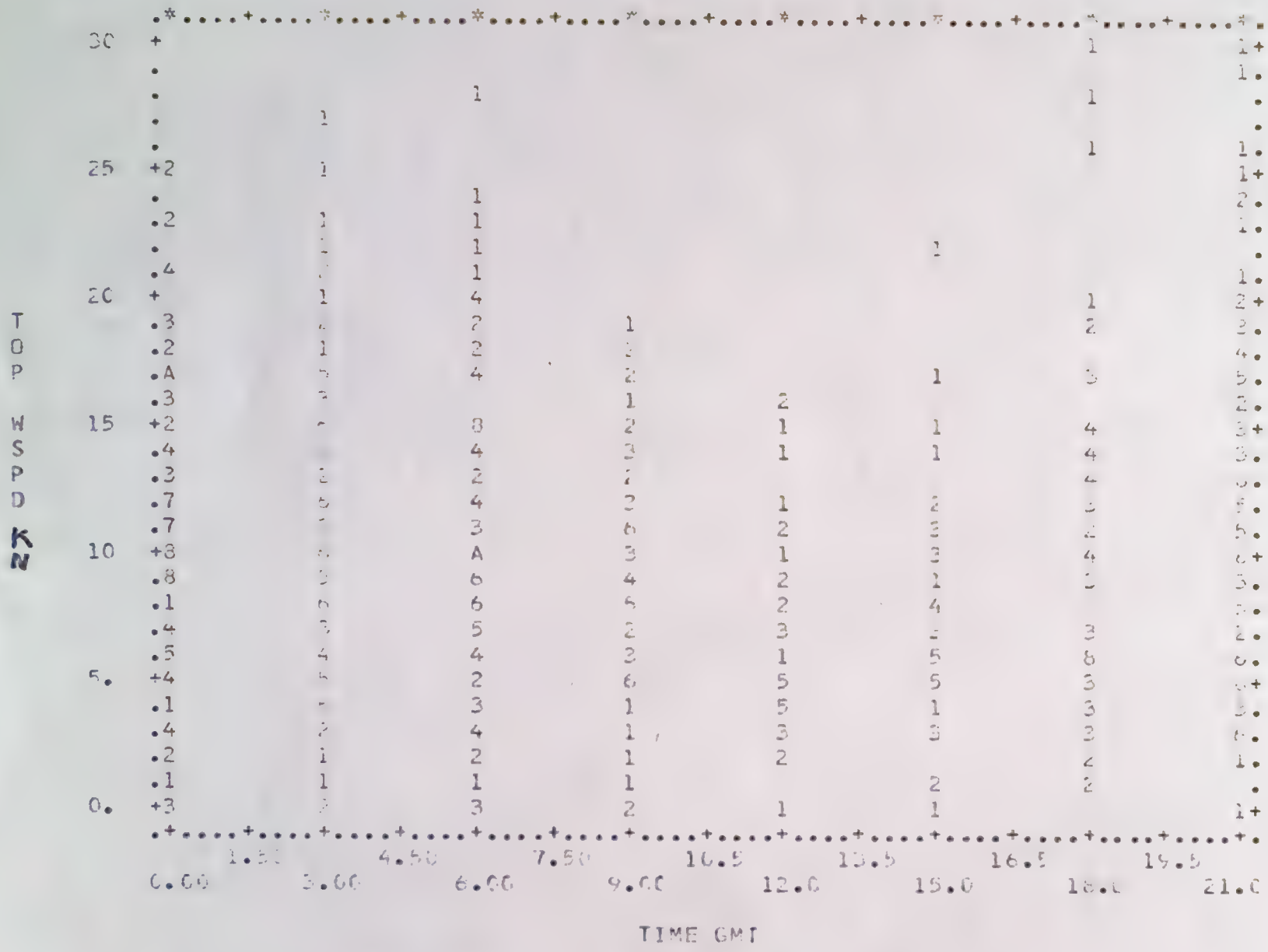
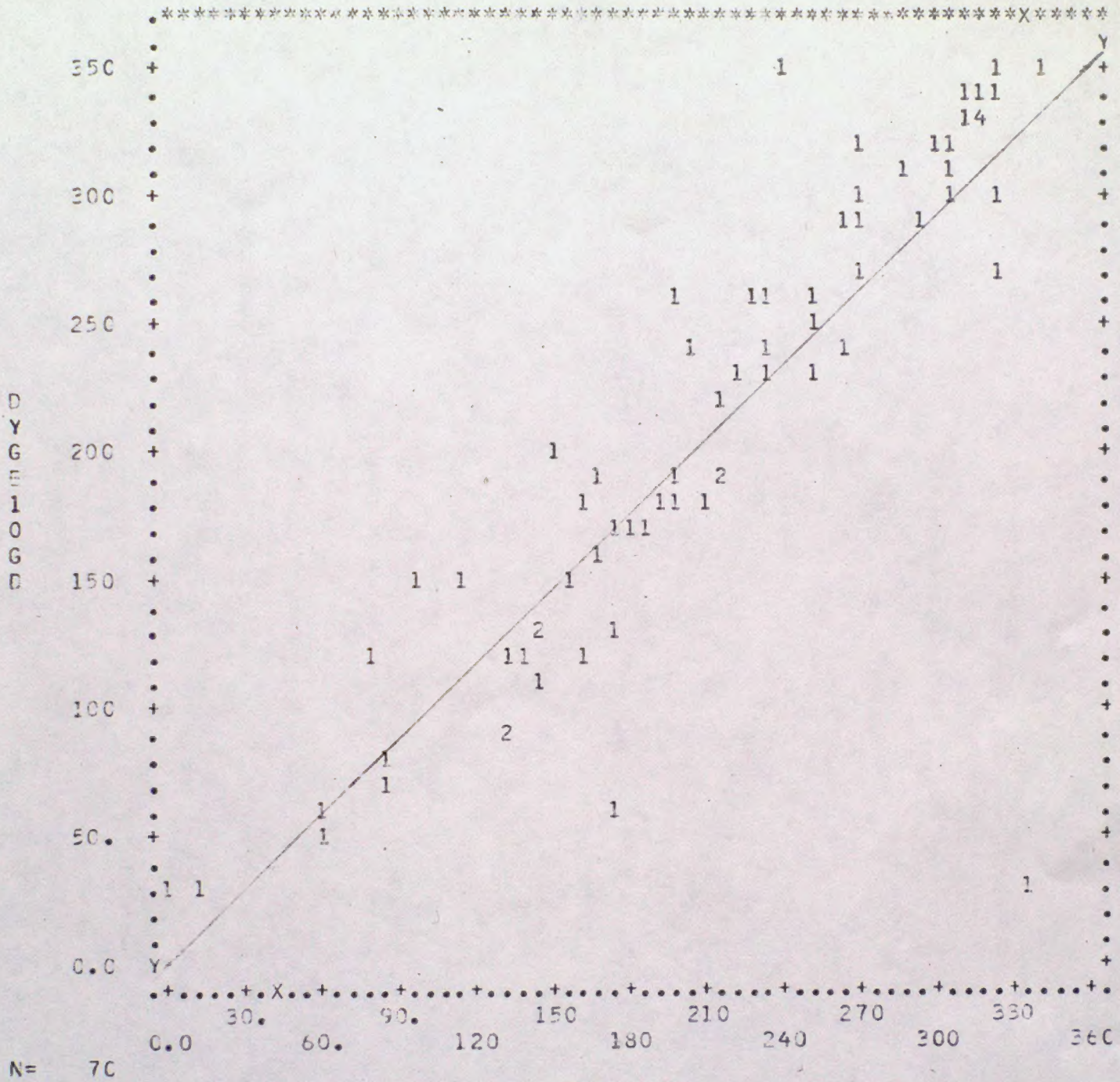


Fig 5 Distribution of Tower Wind Speeds throughout day

Appendix



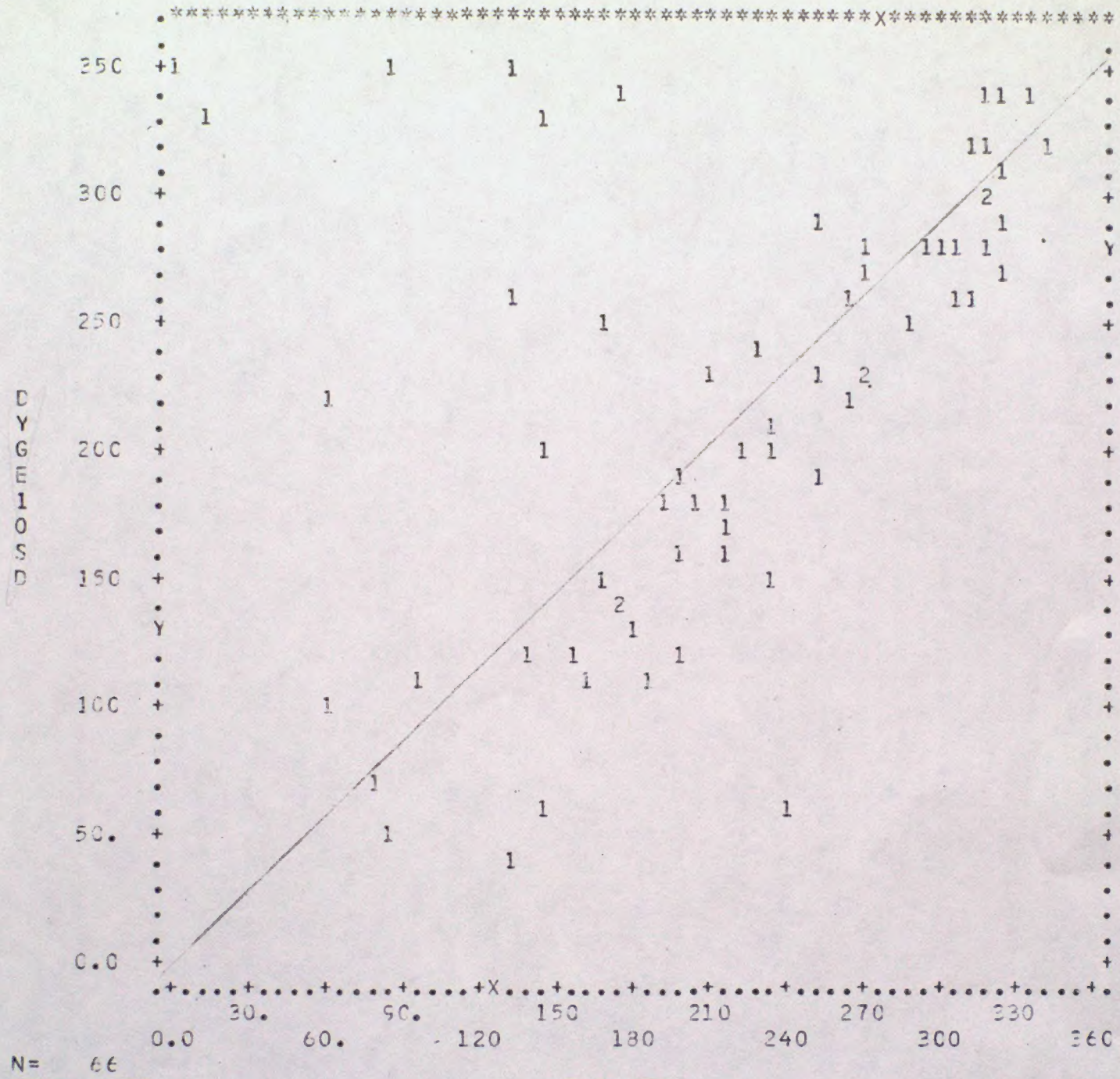
N= 70
COR= .860

	MEAN	ST.DEV.	REGRESSION LINE	RES.MS.
X	213.70	84.691	X= .76773*Y+ 50.284	1890.0
Y	212.86	94.916	Y= .96430*X+ 6.7854	2373.9

Fig A Scatter Plot of Geostrophic Wind Direction against Tower Wind Direction

$V_T \geq 10$ kn Period 0900-1800

Appendix



N= 66
CCR= .407

	MEAN	ST.DEV.	REGRESSION LINE	RES.MS.
X	215.59	84.980	X= .39872*Y+ 127.39	6119.5
Y	221.21	86.745	Y= .41545*X+ 131.65	6376.3

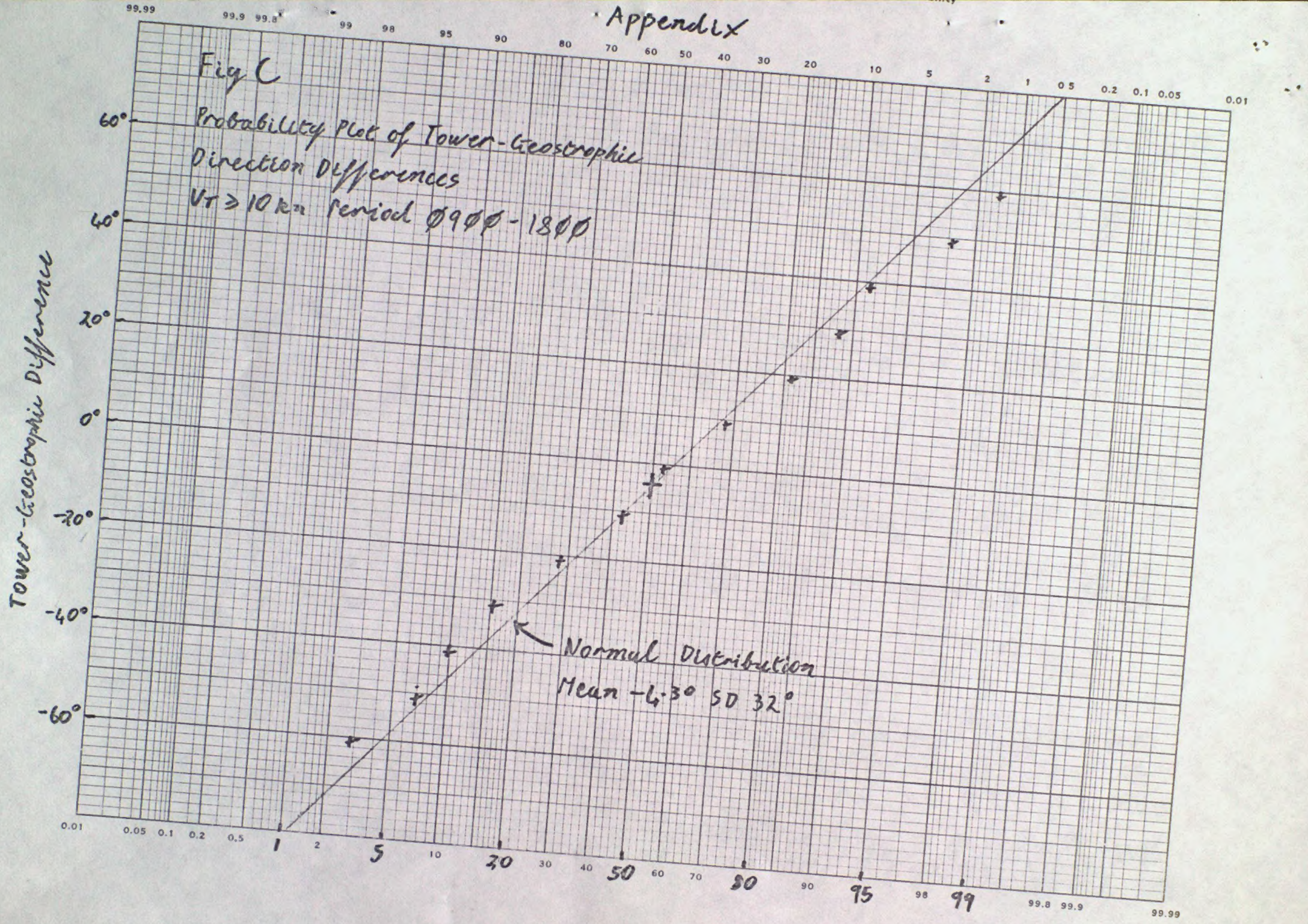
Fig B Scatter Plot of Surface Wind Direction against Tower Wind Direction

$V_T \geq 10$ Kn Period 0900-1800

Fig C

Probability Plot of Tower-Geostrophic Direction Differences

$V_T \geq 10$ kn Period 0900-1800



Appendix

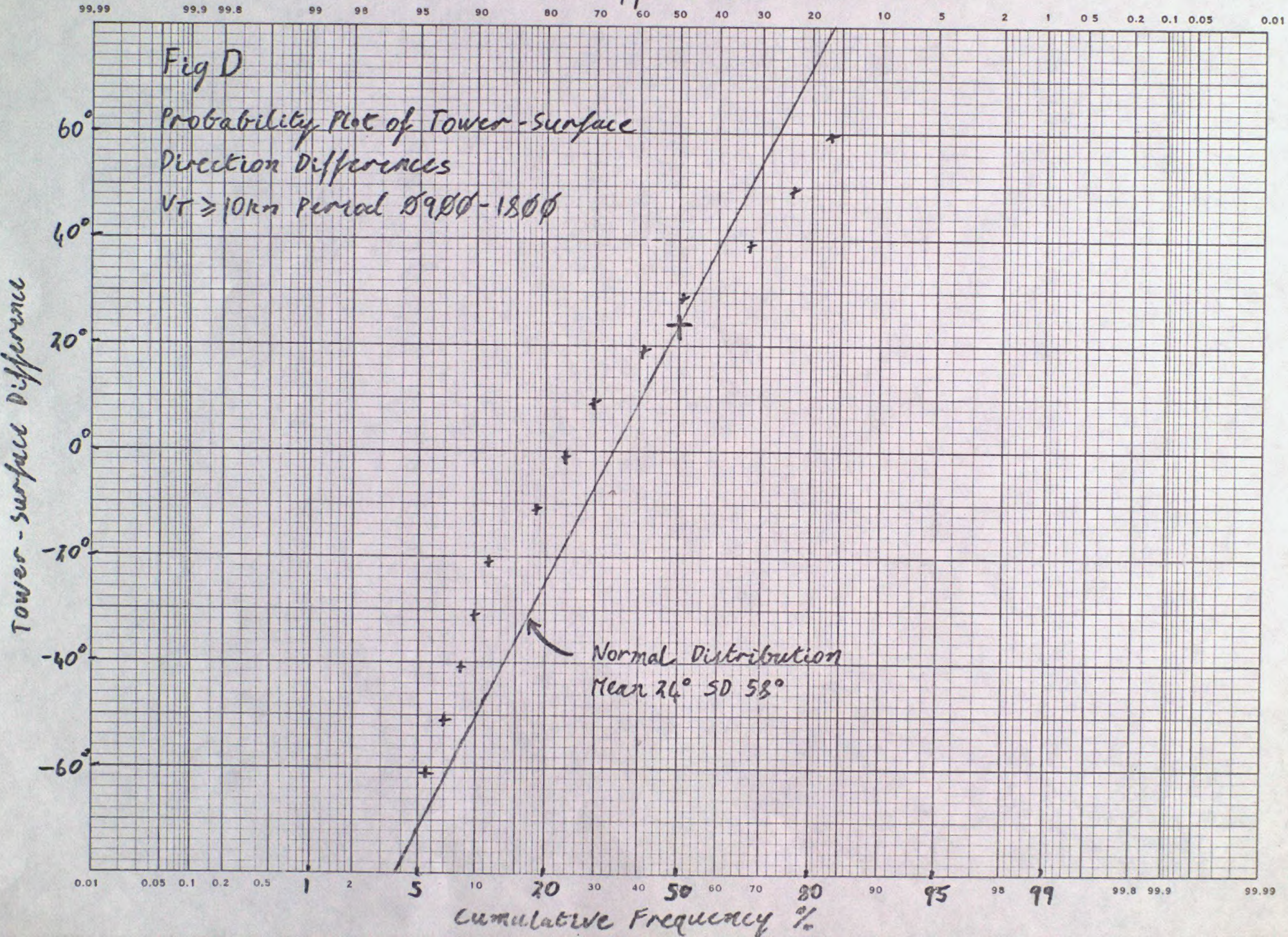


Fig D
Probability Plot of Tower-Surface
Direction Differences
VT ≥ 10km Period 0900-1800
Tower - Surface Difference
60°
40°
20°
0°
-20°
-40°
-60°
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
Normal Distribution
Mean 24° 50 58°
Cumulative Frequency %